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A Novel Approach of a Planar Multi-Band Hybrid Series Feed Network for Use in Antenna Systems Operating at Millimeterwave Frequencies

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Abstract: Recent advances in the development of multi-band antenna systems have focused on the radiating element. With the advent of antennas such as the notch antennas, radiating elements capable of broadband (DC – 50 GHz) operation have been developed. The problem of how to feed the radiating elements has not been adequately addressed. The corporate feed architecture has been the architecture of choice for feeding these elements. However, for applications where the feed loss is critical, the corporate feed architecture does not present a feasible solution. Other traditional low loss planar feed techniques, such as the series feed and its variations, suffer from narrow operating bands. In this paper, we describe a novel planar hybrid series feed network which exhibits the very low loss properties of the traditional series feed by modifying the resonant structure to operate at multiple distinct bands.

1. Introduction

With the increased demand for commercial in-flight entertainment and communications systems, coupled with the Military's continued reliance on satellite-based communications for the battlefield of the future, there is a continuing push to advance low cost antenna systems capable of operating at multiple bands. In addition to the low cost requirements, significant space restrictions are being placed on these systems. To meet these demands, it has become necessary to develop wideband antenna systems capable of operating at multiple frequencies in a single aperture. While there have been strides to develop wideband radiating elements, little progress has been made when it comes to the feeding structure. In addition to requiring the antenna aperture to operate at multiple frequencies, there is a continuing call to reduce the overall size of the aperture. In order to reduce the size of the aperture and still be capable of closing the satellite communication link, components such as the feed, which had previously been ignored, must be designed to significantly reduce the losses associated with the feed. This requires moving away from the higher loss corporate feed structure that traditionally has been used as the feeding structure. With the high losses associated with the corporate feed and the narrow bandwidths associated with series feeds, it has become necessary to define a

new hybrid feed architecture which takes advantage of the low loss properties of the series feed while being capable of operating at multiple bands. In this paper, we will present two different planar hybrid architectures that have been designed to operate at dual and tri bands while maintaining low loss characteristics.

2. Definition of Problem

For millimeter wave satellite communications, the common bands are 20 GHz for receive and 30/44 GHz for transmit. Since the goal is to provide all communication functions in a single aperture, the feeding structure must be capable to operate at the multiple transmit and receive bands, compact, low profile and meets the gain requirements at millimeter frequencies. One solution would be to use a separate series feed for each of the frequency bands. However, this significantly adds to the cost and the complexity of the feed. It is desired to have a single feed structure capable of operating at all of the frequency bands of interest, or at the most two separate feed structures (one for the transmit bands and one for the receive bands). In order to meet all of the requirements, it is necessary to define a new class of hybrid feeding structures that combine the bandwidth properties of the corporate feed with the low loss properties of the series feed.

3. Previous approach:

There are many feed topologies and mechanisms available, not just to couple energy to individual elements, but also to control distribution (for example, tapered illumination, phase shift, ..etc...) of energy in a linear or planar array of elements. A variety of those feed topologies have been surveyed in literatures [1-3]. A list of those electrical and packaging constraints which influence the choice of the feeding architecture are given in Fig.1.

The corporate feed is among the most commonly used architecture, where the feed is divided into two paths and each path divides in a binary order and so on, using the standard impedance split [3], Wilkinson divider [4] or Lange coupler [5]. Sometimes, the divider includes 3 or 5-ways divides [3]. In theory, an instantaneous broad bandwidth could be achieved using this topology. But in practice, the desire to have a low profile and light weight full size phased arrays of hundreds or thousands of radiating elements systems for satellite-on-the-move (SATOM) applications, that require a minimum net gain of 35 dBi, eliminates the feasibility to have this feed on a stack that is co-planar to the array. In other words, the overall depth of the feed structure is going to be a significant problem in an aerodynamics sensitive application. Also, the loss factor arises from line dissipations and reflection from junctions. Another avenue is a multilayer approach but the interconnect loss dramatically increases proportional to the number of layers in the millimeter frequency ranges [6]. Adding low noise amplifier (LNA) might not be attractive because it will add another figure of complexity in the multilayer package and will increase the cost. The series feed has a narrower bandwidth because of its dependency on the resonant frequency [1, 2].

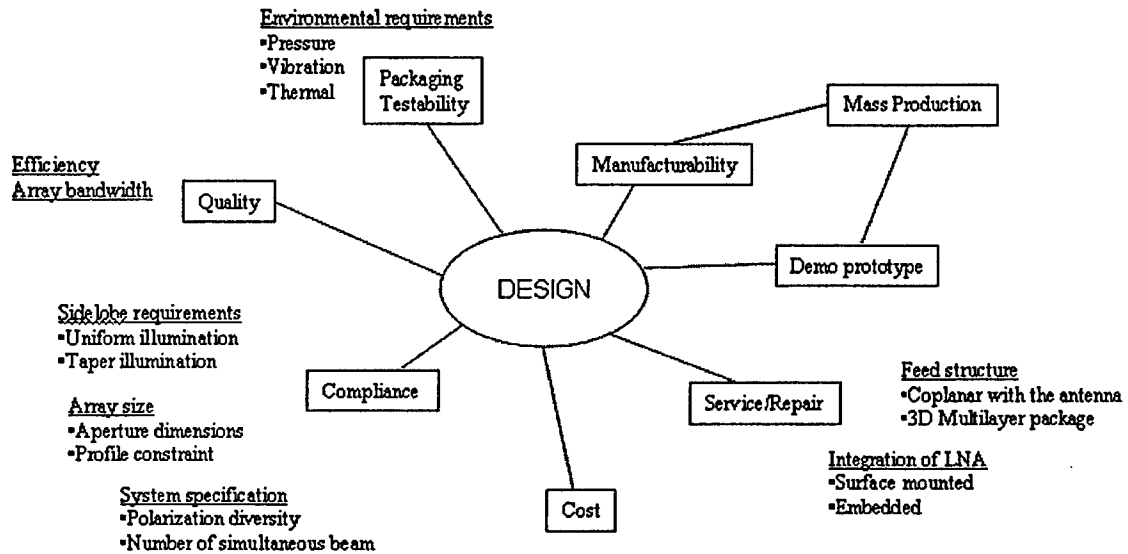


Figure 1: Concurrence of a design to determine of feed structure

A broadband space fed array offers a low-cost alternative whenever multiband feed and beam squint constraints will allow [7,8]. However, the focal/depth ratio of the lens is always a concern. Secondly, such configuration requires a broadband true time delay phase shifter such as MEMs technology [9] used to enable beam shaping and electronic steering functionalities. MEMs are still in the premature stages and there is an issue of the long term reliability [10], which effects the applicability of this approach.

There are other arrangements of feeds that phased array engineers have used; however, the intent of this section is to exhibit a top level summary of the key attempts and challenges in achieving a broadband feed network.

4. Planar Multiband Hybrid Series and Corporate Feed Network

a. Feed Structure

With the above background, there was a demand to reveal the fundamental properties of electromagnetic waves and circuit theory, to go beyond the conventional feed topologies and propose a multiband hybrid series feed solution that is illustrated in Fig. 2.

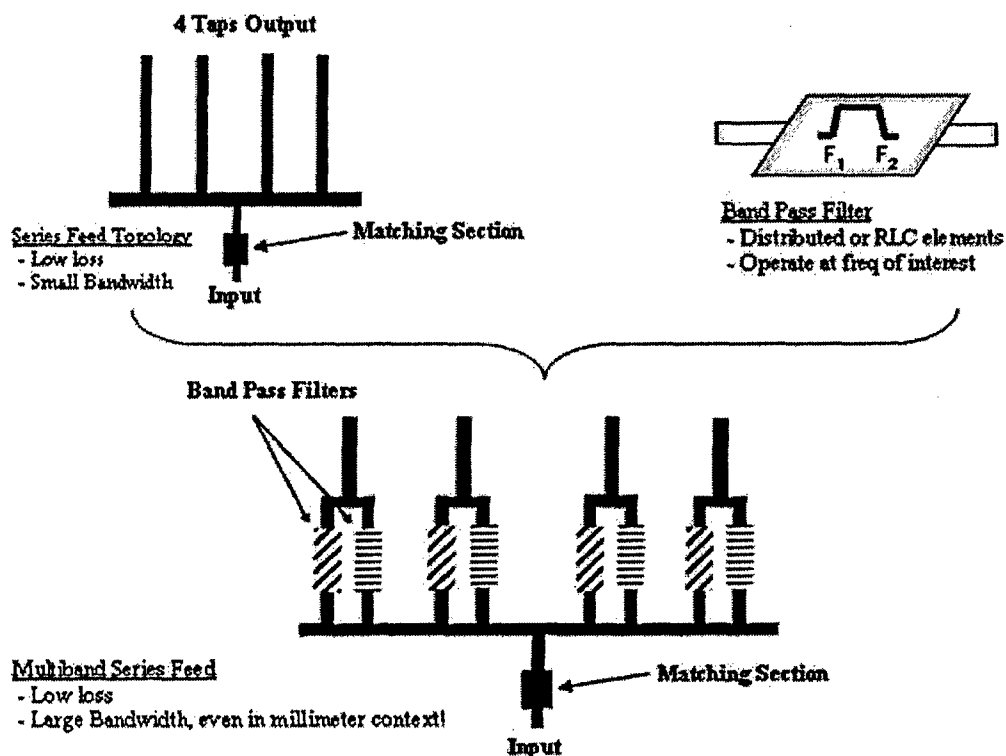


Figure 2: Multiband Hybrid Series Feed Architecture

Similar to the conventional series feed, the multiband hybrid series feed can be fed either from the edge or from the center and is terminated with an open circuit(s). The coupled series line is modified to include multiple sub tap lines for each frequency band. The taps are superimposed by band pass filters that tune the resonance response of that tap line to the desired frequency band. The outputs of the individual frequency sub tap lines are combined after the filtering stage to form a multiband tap line. The spacing between the sub tap lines and the open circuit and their impedances are optimized to provide the desired performance.

For applications requiring more feed tap-lines than a single branch can support, as depicted in Fig. 2, branches can be cascaded together to provide additional tap lines. Figure 3 depicts a solution for a dual band feed in a 16 element array.

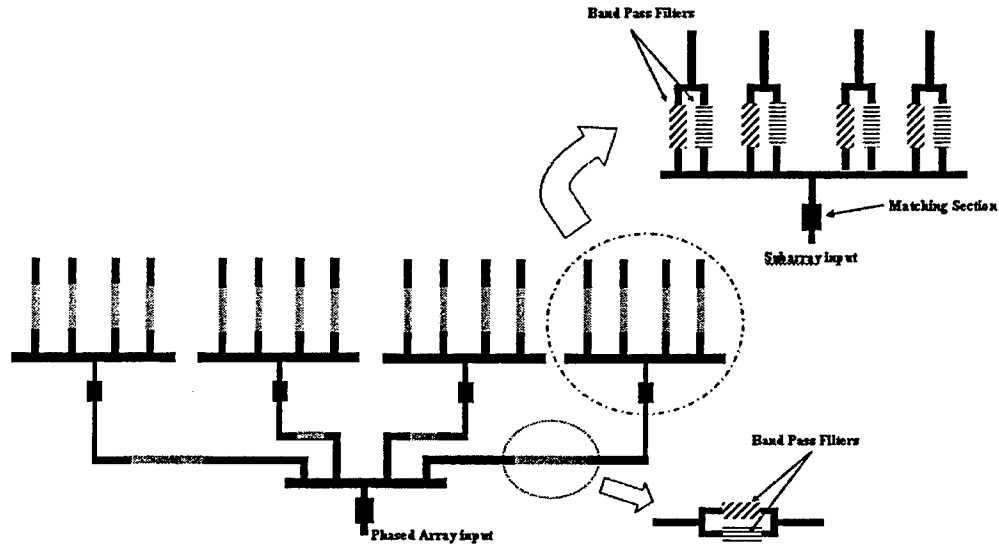


Figure 3: Multi-branch, dual-band hybrid series feed realized from a single branch

The bandpass filters used in the sub tap lines can take any form, including distributed and lumped elements [11, 12]. Selection of the filter architecture is application driven and is determined by factors such as acceptable loss, available space, useable line widths, and/or the periodic nature of the distributed network.

Another feature of this new hybrid-series feed is that it provides substantially uniform and tapered illumination at the output tap-lines. It exhibits an ultra-low loss performance compared with the two distinct types of feed: corporate and series or their combination. The hybrid series feed discussed here can be extended to cover a tri-band operation as shown in Fig. 4.

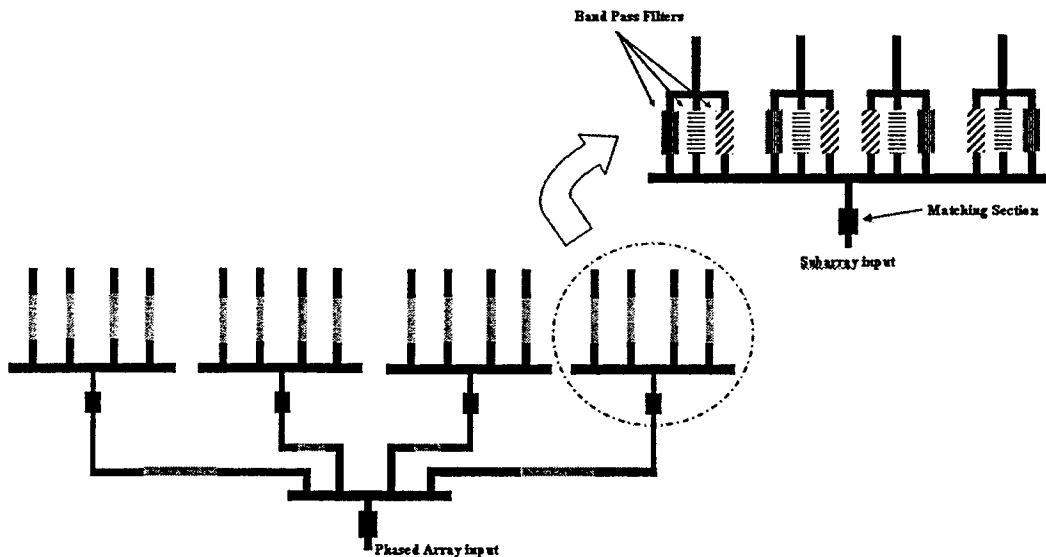


Figure 4: Multi-branch, tri-band hybrid series feed realized from a single branch feed

Additionally, it can be expanded to as many as output taps as desired while preserving the operational bandwidth of the array and the low feed-loss. An example is shown in Fig. 5.

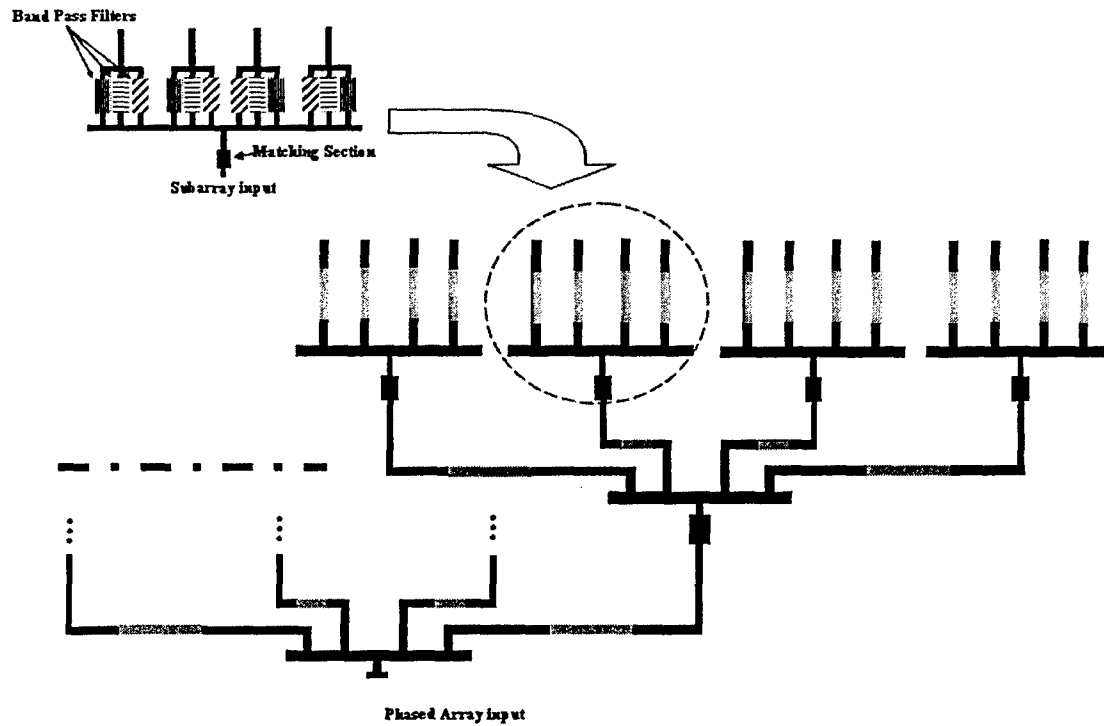


Figure 5: Multi-branch, tri-band hybrid series feed realized from a single branch

A known drawback with the above novel approach is that the more operating bands are desired, the wider the circuit is to be because of the filter components, so a packaging engineer might have a difficulty in assembling all the sub-tap lines behind a single radiating element.

In applications where the circuit width is more critical than the depth, the hybrid series feed may not be applicable due to the required circuit width. A second hybrid series circuit feed topology that allows the width of the circuit to be constrained at the cost of increasing depth is the Hybrid Corporate Feed. The Hybrid Corporate Feed is a modification of the traditional corporate feed that is widely used. The principle of operation for the corporate feed is based on impedance division. A graphical representation of the traditional corporate feed is shown in Fig. 6.

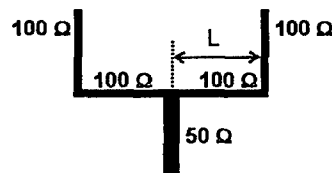


Figure 6: Graphical representation of a traditional corporate feed

In the traditional corporate feed, the distance between the branches (L) can be set as desired. The branch impedance is chosen such that the output ports are matched to the input feed line. In theory, if the dielectric constant of the substrate remains constant over frequency, the power split would be constant over frequency. However, the bends introduce a capacitive loading which causes the power split to vary with frequency (see Fig. 8).

In the alternative hybrid corporate feed architecture, shown in Fig. 7, the distance between the branches of the circuit is fixed to the desired value. The impedance of the branch arm, feed line, and matching sections are optimized to provide the desired response. By choosing the proper combination of the line impedances and lengths, the circuit exhibits a resonance response at the desired frequencies. Through optimization, the circuit can be designed to provide a constant power split over the designed frequency bands, as shown in Fig. 8.

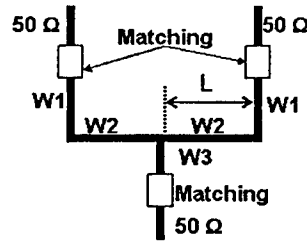


Figure 7: Graphical representation of the proposed hybrid corporate feed

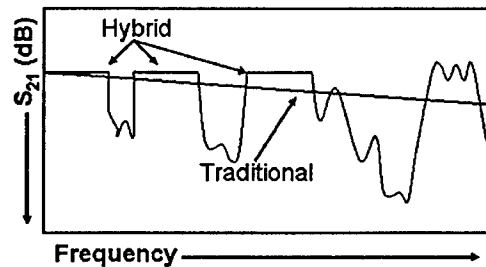


Figure 8: Graphical depiction of hybrid vs. traditional corporate feed performance

b. Simulation Results

The two circuit topologies, the Hybrid Series Feed and Hybrid Corporate Feed, were simulated using Agilent ADS. The circuit board parameters used in the simulations are shown in Table 1. The loss tangent, $\tan\delta$, was set to zero to eliminate the effect of the dielectric loss allowing the simulation to reflect the ideal performance of the circuit design.

Table 1: Simulation Properties

ϵ_r	3.0
μ_r	1.0
Ground Plane Spacing	20 mils
Conductor Thickness	17 microns
$\tan\delta$	0

Figure 9 shows a graphical representation of a section of the simulated Hybrid Series Feed circuit topology. The Hybrid Series feed model consisted of 1:32 power divider optimized for operation at three simultaneous bands. The resulting $S_{1,x}$ magnitude over the three operating bands should be -15.052 dB for a perfect power split. The results of the simulations are shown in Fig. 10. The $S_{1,x}$ results are within 0.15 dB of the expected value.

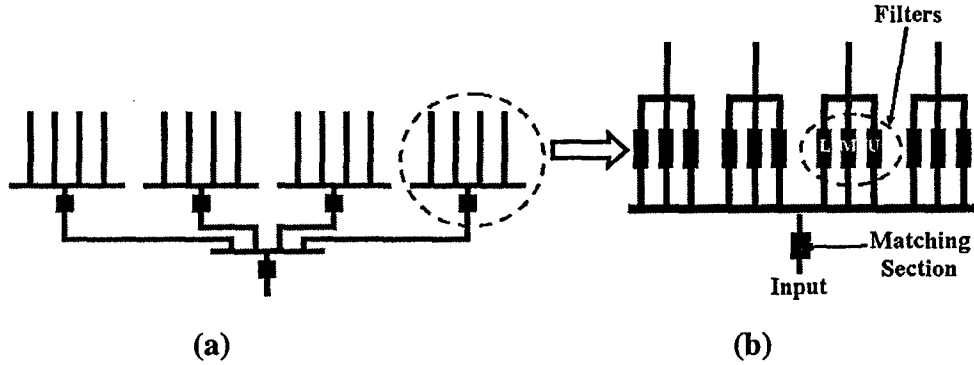


Figure 9: (a) Hybrid Series Feed (b) close up view of one branch

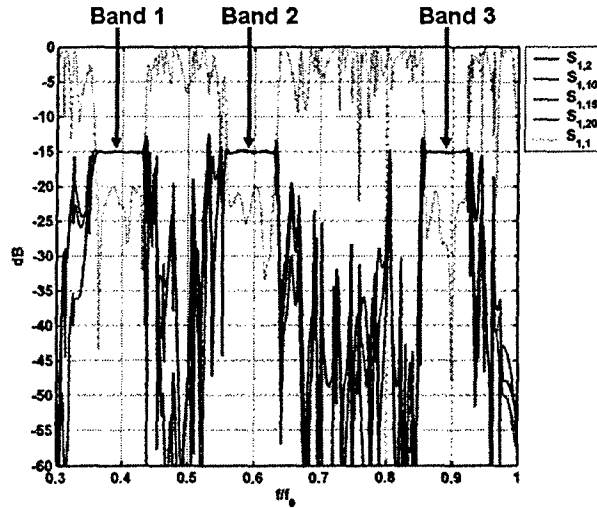


Figure 10: Simulation results showing the normalized frequency response of a 1:32 power divider utilizing the Hybrid Series Feed architecture

The second simulated circuit topology was the Hybrid Corporate feed, a section which is depicted graphically in Fig. 11. The Hybrid Corporate feed modeled consisted of a 1:64 power divider optimized for operation at three simultaneous bands. The resulting $S_{1,x}$ magnitude over the three operating bands should be -18.02 dB for a perfect power split. The simulated results are shown in Fig. 12. The achieved $S_{1,x}$ results are within .15 dB of the expected value.

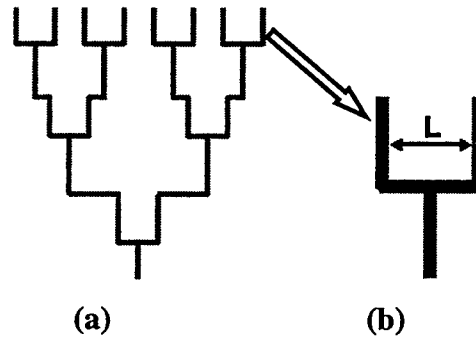


Figure 11: (a) Hybrid Corporate Series Feed (b) Single branch

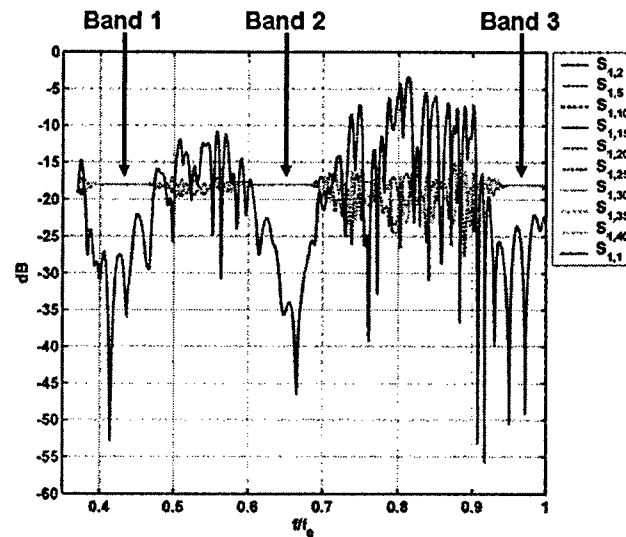


Figure 12: Simulation results showing the normalized frequency response of a 1:40 power divider utilizing the Hybrid Corporate Series Feed architecture

5. Conclusion

This paper describes new approaches for multiband hybrid series and hybrid corporate feeds, that provide additional feed topology and design options for the phased array engineering pool. Results of simulation data have been presented in this paper as evidence that a meaning-full broadband feed can be achieved using a combination of traditional resonance feed tap-lines and RLC circuitry. If the number of desired operating bands is too large to fit in the circuit assembly behind a single radiating element, one can consider the hybrid corporate feed by adding more matching sections where the loss factor has been quantified and shown to be dependent on the mismatch of the junctions and bend. The above results are preliminary and further work is on-going to consolidate the analysis.

6. References

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